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THE EFFECT OF TARGETS HAVING SELECTED LINE WIDTH TO SPACE WIDTH RATIOS
ON SPURIOUS RESOLUTION AND RESOLVING POWER

by

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A thesis submitted in partial fulfillment of the
requirements for the degree of Bachelor of Science in the
School of Photography in the College of Graphic Arts and Photography
of the Rochester Institute of Technology

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Thesis adviser: Professor G. W. Schumann

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TABLE OF CONTENTS

List of Tables	iii
List of Figures	iv
Abstract	1
Introduction	1
Apparatus and Procedure	5
Evaluation and Results	15
Discussion and Conclusions	17
Appendix	25
Bibliography	29

List of Tables

Table 1	List of Target Ratios	8
Table 2	Resolving Power versus Log of Target Ratio	8
Table 3	Spurious Resolution Exposure Times	12
Table 4	Resolving Power Exposure Times	12

LIST OF FIGURES

Figure 1	Apparatus Used to Make Radial Targets	6
Figure 2	Razor Mask	6
Figure 3	1:1 Target on 6127 Film	9
Figure 4	Target Image Showing Spurious Resolution	9
Figure 5	Experimental Apparatus	11
Figure 6	Drawing of Focus Monitoring Device	11
Figure 7	Transmittance Pattern	18
Figure 8	Spurious Resolution Diameter versus Lens Defocus Positions	21
Figure 9	Kodak 5069 High Contrast Copy Resolving Power versus Log of Line to Space Width Ratio	22
Figure 10	Kodak Tri-x Resolving Power versus Log of Line to Space Width Ratios	23
Figure 11	Modulation versus Target Line to Space Ratio	24
Figure 12	Schematic Diagram of Apparatus Used to Observe Transform	27
Figure 13	Representation of Transform of 1:1 Radial Target	27
Figure 14	Frequency Spectra and Fourier Transforms at a Fixed Frequency of Crenelate Analogues of Targets Used in Testing	28

ABSTRACT

Six radial targets having different line width to space width ratios were made. The effect of the ratios on the phenomena of spurious resolution and resolving power was studied on a fine grain and a coarse grain film. Spurious resolution patterns were undetectable when the dark space exceeded five times the width of the bright line. Resolving power values reached their maximum when the target contained lines that were one-fifth the width of the dark spaces between them.

INTRODUCTION

This project investigated concepts in resolving power and spurious resolution, using a series of radial targets, varying in line to space width ratio. Although resolving power techniques have lost some of their eminence, they are still widely used, justifying efforts aimed at understanding related phenomena.

The concept of resolving power and techniques enabling its use in the measurement of photographic performance have been devised since the first attempts at evaluating imaging systems. The past two decades have seen the introduction and development of transfer function techniques in photographic systems evaluation. This relatively sophisticated procedure has overshadowed resolving power. Subsequently, there have been suggestions of relegating resolving power to obsolescence. Resolving power is likely to remain in usage for some time. Brock¹, reviewing image evaluation techniques in 1965, noted that modulation transfer functions are a more complete evaluation of lens performance than a resolving power figure. However, Brock¹ and Perrin² both agree that resolving power tests are the simplest that give quantitative answers about the object under test and that all factors that affect image quality are taken into account. The economic advantages of this procedure are significant as well.

The literature search disclosed the first mention of spurious resolution in conjunction with image evaluation was made by F.E. Washer³

in a 1939 National Bureau of Standards lens testing paper. He cited an earlier reference in the field of Ophthalmology⁴, and noted that no thorough analysis had been made. Later, others^{5,6} report the effect in test pattern images. Schade⁷, in 1948, formulated a quantitative method which predicted the maxima and minima of the spurious image of a high contrast Vannate target with a 1:1 line to space width ratio, reproduced on a television tube. Based on the concept of overlapping of the out-of-focus images, and requiring knowledge of the intensity distribution of the image, the formula is written as follows: $r_{\Delta\psi} = \psi_N / \psi_0$. $r_{\Delta\psi}$ is the amplitude factor, and ψ_N / ψ_0 is the ratio of the flux amplitude at line N to the flux amplitude at N=0. N is the number lines of millimeter.

A paper co-authored by Washer⁸, in 1951, was the first devoted to spurious resolution in photographic lens testing. The authors concluded that spurious resolution could be explained without recourse to diffraction theory. Using Schade's method, spherical aberration data, and a high contrast multiline target⁹, they predicted the light intensity distribution of the spurious image. The authors also demonstrated that counting the number of lines in an image of a multiline target will not always detect spurious resolution. Perrin² showed that a lens with a square topped, or crenelate spread function, will create a response function curve with oscillations which are negative, and that this lens¹⁰ affects spurious resolution far more readily than other types of lenses.

One of the shortcomings of resolving power measurements is the high degree of variability of the results¹. A possible source of the

problem could be the use of many different forms of targets^{11,12}. A standard has been agreed to, which helps reduce target variability, and specifies that a tri-bar target having a 1:1 ratio shall be used. It has been seen from the literature that the image produced from repeating pattern targets with the 1:1 ratio, produced spurious resolution images. The 1:1 spacing produces a frequency spectrum that only contains the odd harmonics, not a frequency structure that is representative of most practical situations. A natural criterion for image sharpness in practical photography is the sharpness of a line. The spectrum of a line is that of a delta function. Line to space ratios making the line smaller, in a target, produce spectra similar to the line spectrum. This suggests that line to space ratios other than 1:1 spacing might be preferable.

The target chosen was the pie-shaped, or star target. Perrin and Altman¹² proposed to establish a specific nomenclature for the various targets, and the term "radial" was chosen to denote this particular target.

Jewell¹³, in an early study, concludes that the radial target is the most satisfactory for lens testing. Later papers show a shift to the bar target, and for reasons called "somewhat arbitrary" by Perrin¹⁰, it has been chosen as a standard. The radial targets in the literature all have a 1:1 line to space width ratio. Sandvik¹¹ suggests that the discrepancy in resolving power numbers obtained with radial and bar targets might be partially accounted for by the 1:1 ratio. He proposes studies to determine a radial target ratio to make the results

equivalent.

In an allied area, Sandvik¹¹ made studies of the change in resolving power when the line to space ratio was altered. He reported that for a two bar, high contrast target, the resolving power increased as the log of the ratio decreased, over the range of ratios tested.

The original objective of this paper was to use a series of line to space ratios in the target, and observe the change in spurious resolution effects in the image at a specific defocus position. The scope of the project was enlarged after commencing work, to include resolving power comparisons, and a comparison of the Fourier transforms of the radial target with the three bar target in use today.

APPARATUS AND PROCEDURE

The choice of the radial target was deliberate. It can be thought of as a concentric arrangement of crenelate patterns of decreasing frequency, starting at the center. There is a high information content per exposure. The target images are very regular in geometry and produce a spurious resolution pattern that is readily evaluated.

The targets were made for this project, as none, save the 1:1 line to space ratio, were available. The method is outlined as follows and is shown in figure 1. A wedge mask, using two razor blades was made and projected onto the surface of the rotary table, the point of the wedge aligned with the center of the table. The number of degrees subtended by the wedge for the different target ratios is shown in table 1. The measurement of the number of degrees in the projected wedge was accomplished with a protractor placed in the image plane. The protractor could be read to 15 minutes of arc. Successive exposures and rotations of the table produced the radial pattern on Eastman Kodak 6127 negative 4x5 sheet film. The rotary table could control motion to within 0.25 seconds of arc. The results were six high contrast radial targets with the line width to space width ratios listed in table 1.

The line width to space width ratio, or, the line to space ratio, refers to the relative amounts of exposed and unexposed portions of film subtended by the six degree angle comprising a wedge. Each wedge com-

135 mm GLASSLESS NEGATIVE CARRIER

TAPE

TWO RAZOR BLADES



FIGURE 2: RAZOR MASK

ENLARGER

NEGATIVE CARRIER MOUNT

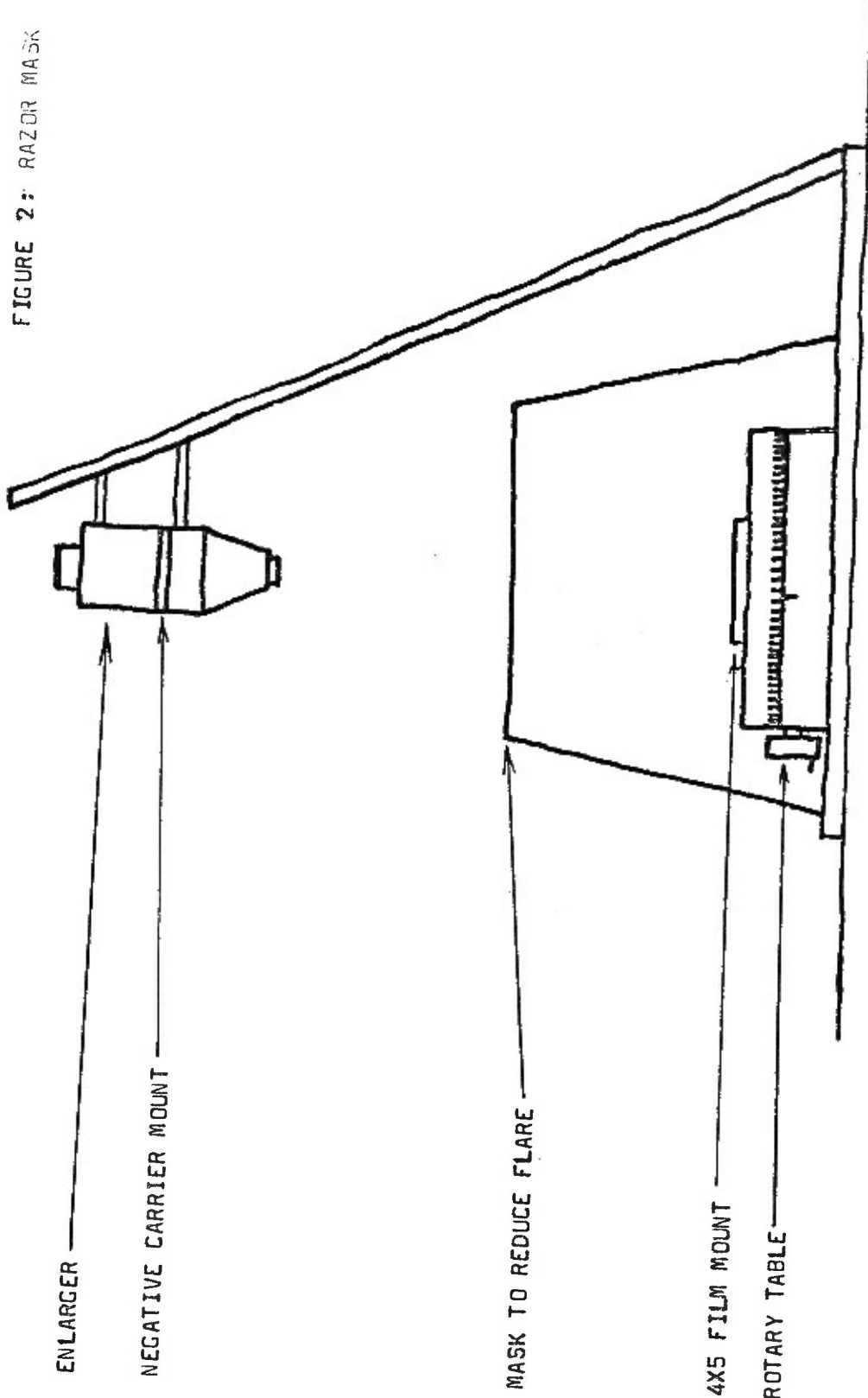


FIGURE 1: APPARATUS USED TO MAKE RADIAL TARGETS

Details of Radial Target Manufacture

Targets made on Eastman Kodak 6127 Commercial 4X5 negative Sheet Film

Processing: DK-50, 1.5 min., 75°F; Kodak Indicator Stop Bath, 0.5 min., 75°F; Edwal Hi Speed Liquid Fix, 4 min., 75°F; Washed for 1 hour; Dried for 20 hours at 79°F and 68% Rel. Humidity.

Safelight: Wratten # 25

Enlarger: Omega D-2 Variable Condenser. Condenser lenses- 6 and 3/8 inches

Enlarging Bulb: G.E. PH211, 75W, 115-120 V.

Enlarging Lens: Ilex f/4.5. Stops down to f/22. Was set at f/8. 2 inch focal length.

Exposure Time: 1.6 Seconds.

Mask: Two Gillette Platinum razor blades. The edges were examined with a microscope and determined to be free of defects. They were then mounted on an Omega 135mm size glassless negative carrier with Scotch Photographic tape.

Target film was placed 16 inches from lensboard.

Target film was mounted on an 18 inch Brown and Sharpe rotary table.

Point of wedge image, target film and rotary table were aligned with the optical axis of enlarger.

Refer to table 1 for the wedge image dimensions for the different targets.

Table 1
LIST OF TARGET RATIOS

60 PAIRS OF WEDGES, 1 EXPOSED, 1 UNEXPOSED, PER TARGET

6 DEGREES OF ARC PER CYCLE OF ONE WEDGE PAIR

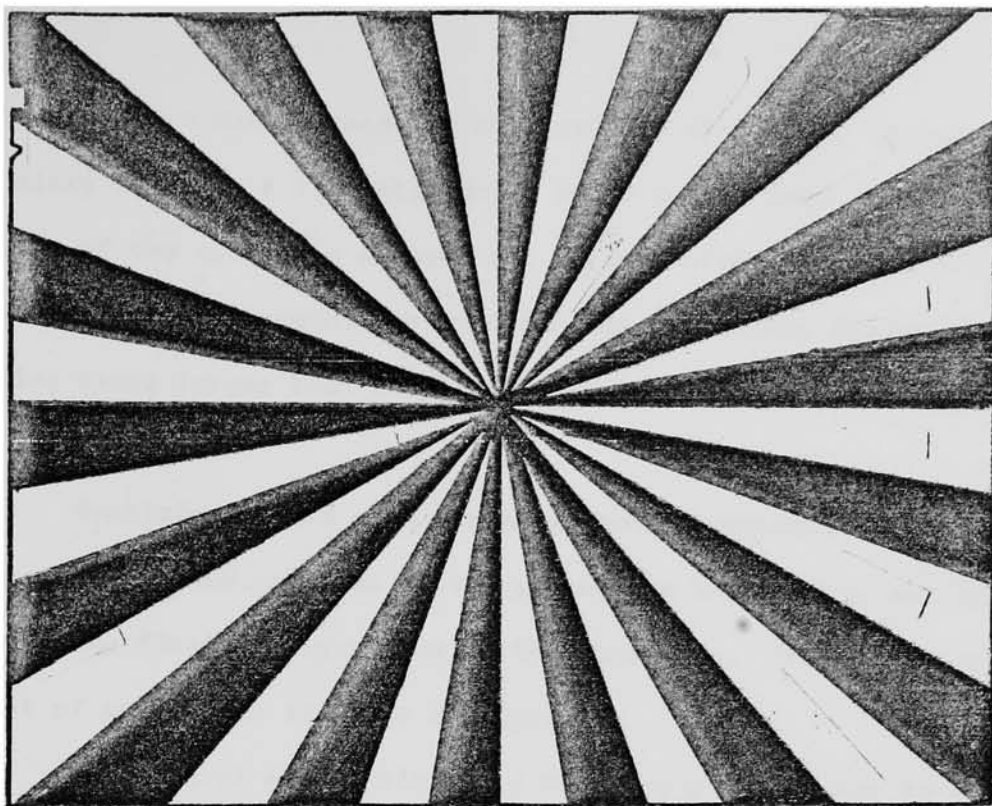
RATIO	Exposed Wedge : Unexposed Wedge	Degrees Exposed Per Cycle	Log of Ratios*
0.5	: 1	1°	0.30
1	: 1	3°	0.0
2	: 1	4°	1.70
3	: 1	4.5°	1.48
5	: 1	5°	1.30
7	: 1	5.25°	1.14

* Sandvik expressed results in the log of the target line to space ratios. The author elected to follow that precedent for the sake of continuity.

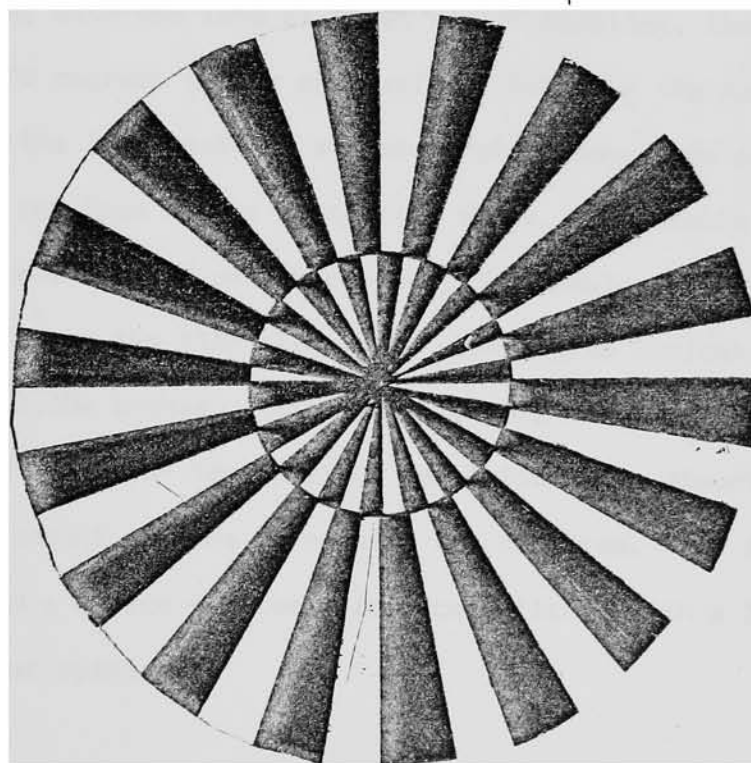
Table 2

Log of Ratio	Resolving Power	
	HCC 5059	Tri-X
0.30	147 c/mm	59 c/mm
0.00	158 c/mm	76 c/mm
1.70	162 c/mm	77 c/mm
1.48	165 c/mm	79 c/mm
1.30	173 c/mm	85 c/mm
1.14	161 c/mm	75 c/mm

Resolving Power versus Log of Target Ratio



1:1 TARGET ON 6127 FILM
Figure 3



TARGET IMAGE SHOWING SPURIOUS RESOLUTION

posed of a line and a space, is one cycle of the radial target, which has sixty cycles. A 1:1 ratio would refer to the fact that three degrees of the cycle are exposed and three degrees are not. A 5:1 ratio refers to the condition in which the dark space (exposed portion) is five times larger than the line (unexposed portion), per six degree cycle.

Preliminary runs with the experimental apparatus were confined to creating a good spurious pattern, a usable image size, and establishing the final configuration of the apparatus. This final arrangement of components is shown in figure 4.

Lens travel was monitored by mounting a protractor to the front of the camera so that its center was coincident with the center of the camera lens. A pointer was attached to the lens focusing ring to indicate a particular position on the protractor for a given lens position. To illustrate, with the lens at "best focus" position, the pointer might be at 90 degrees on the protractor. Rotating the focusing ring would change the lens position and would also change the position of the pointer, relative to the protractor scale. Repeatable measurements of less than one-half of one degree were obtainable. The amount of lens travel relative to the film plane, for each degree indicated on the protractor, was 0.004 inches. Using this method, the focus series tests were made and a plot of the spurious resolution ring diameter versus the relative amount of lens defocusing was obtained. The images were evaluated with a Bausch and Lomb microscope fitted with a 3.5X objective and a 10X filar eyepiece.

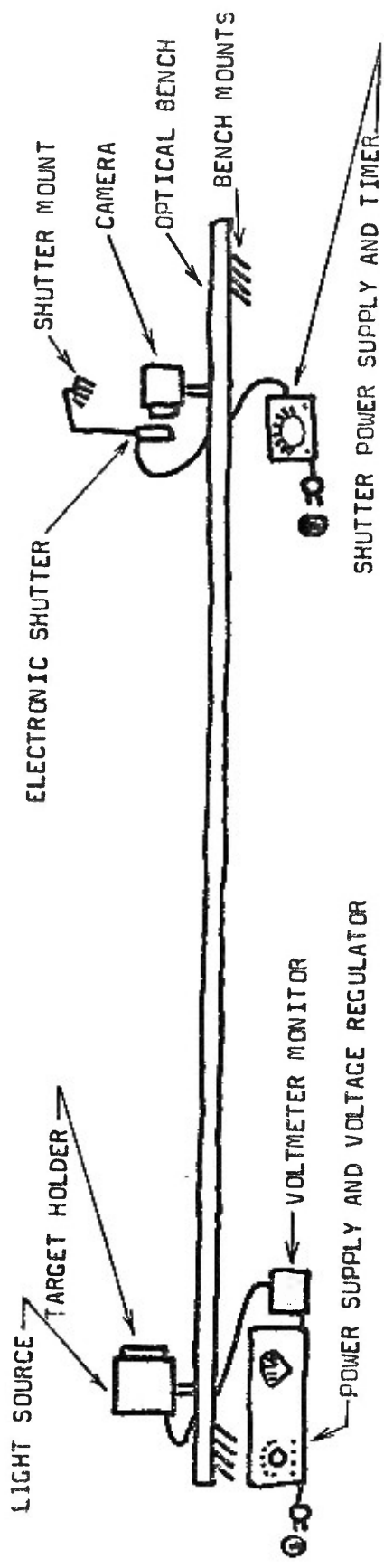
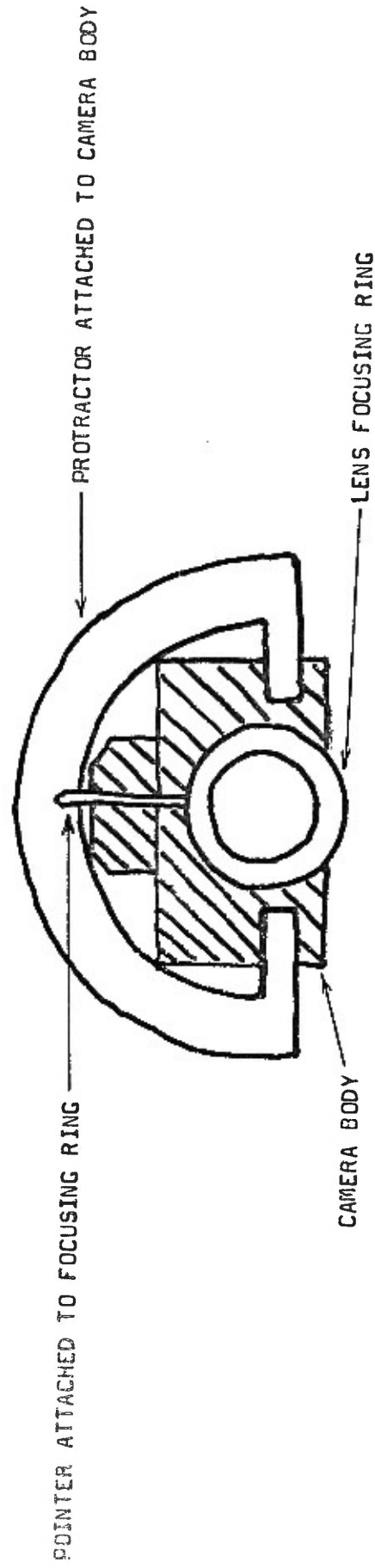


Figure 5

NOTE: SHUTTER IS MOUNTED INDEPENDENTLY, PREVENTING VIBRATION IN OPTICAL SYSTEM WHILE OPERATING.



Drawing of Focus Monitoring Device

FIGURE 6

Experimental Apparatus Data

Optical Bench: R.I.T. Bench permanently mounted in room R-24

Lamp Power Supply: Set at 14 volts

Lamp: Quartz-Iodide Omega enlarger lamp and Omega Chromega enlarger lamp diffuser.

Target Holder: Metal Holder, masked with a 2.93 inch circular aperture, and two 0.8 neutral density filters.

Shutter: Vincent Associates Uniblitz Shutter model #223x1Y0X5, and Uniblitz shutter power supply model #150.

Camera: Nikkormat, 135mm camera

Lens: Nikon 55mm f/1.7 lens set at f/8

Film: Eastman Kodak Tri-X and High Contrast Copy 5069 135mm film.

Process: Per manufacturer's specifications at 68°F.

Target Holder: set at 91.75 cm. mark on bench.

Camera: set at 3 meters, 90 cm. mark on bench

System Magnification: -58.75X

SPURIOUS RESOLUTION EXPOSURE TIMES (in seconds)					
RATIO	EXPOSURE TIMES				
0.5:1	8	4	2	1	$\frac{1}{2}$
1:1	8	4	2	1	$\frac{1}{2}$
2:1	16	8	4	2	1
3:1	16	8	4	2	1
5:1	32	16	8	4	2
7:1	64	32	16	8	4

Table 3

RESOLVING POWER EXPOSURE TIMES (in seconds)										
RATIO	HCC 5069					Tri-X				
0.5:1	8	4	2	1	$\frac{1}{2}$	1/8	1/15	1/30	1/60	1/125
1:1	8	4	2	1	$\frac{1}{2}$	1/8	1/15	1/30	1/60	1/125
2:1	8	4	2	1	$\frac{1}{2}$	1/8	1/15	1/30	1/60	1/125
3:1	16	8	4	2	1	1/4	1/8	1/15	1/30	1/60
5:1	16	8	4	2	1	1/2	1/4	1/8	1/15	1/30
7:1	64	32	16	8	4	1	1/2	1/4	1/8	1/15

Table 4

The work was done on Eastman Kodak High Contrast Copy 5059 negative film as follows. An exposure series was made to determine the optimum exposure for the 1:1 target. This exposure was used in a defocus series. The objective was to find a point where the spurious pattern was least changed by a change in focus of the camera lens, and, if such a point existed, use that defocus setting for the remainder of the spurious resolution work. The accompanying graph shows a slight decrease in the rate of change of the diameter of the pattern near the "ten degree" setting of the protractor, for this particular experimental apparatus.

The exposures for the spurious resolution series were made by defocusing the lens to this ten degree setting. The order in which the different targets were photographed was randomized. A series of five exposures was made with each target. The optimum exposure, (X), and exposures of $1/4X$, $1/2X$, $2X$, and $4X$, were made in random order. All exposures were thrice replicated. The exposure runs were broken into two categories: high contrast exposures, and low contrast target exposures. The high contrast luminance ratio was in excess of 100:1 between the lines and spaces in the target image, and the low contrast luminance ratio produced a density difference of approximately 1.21 between the lines and spaces in the target image. The contrast ratios fell within the specifications outlined in the United States of America Standards Institute standards for high and low contrast targets. The low contrast target condition was achieved by exposing the film to the target image after exposing it to a uniform light source, which raised the background level of the film.

The resolving power series was made by first confirming the best focus position and then evaluating an exposure series made with each target. Both the high contrast 5069 and Tri-x negative films were used. No low contrast resolving power series was carried out.

A graph of the frequency spectrum of the Fourier series and a graph of the fourier transform of each target is included for purposes of comparison. The Fourier series and transforms are taken to represent each target at the same distance from the center, and for only an infinitesimal length along the radius. Precedent for this analysis was established by Perrin⁸.

EVALUATION AND RESULTS

Spurious resolution image data was recorded from microscopic examination of the images as follows. The criterion used to choose the image to be examined was based on the density of the center of the target image. The value of this density was determined to be 0.5 on the most acceptable image made in the preliminary runs. The image in the five exposure series whose center density was closest to 0.5 was evaluated. The evaluated images had center densities ranging from 0.47 to 0.52. The spurious pattern diameter was measured in three directions and these readings were averaged.

The evaluation of the spurious resolution images resulted in the following observations. First, the ring that separates the spurious pattern from the "real" image does not significantly change in diameter regardless of the line to space width ratio of the six targets. The diameter does not change with respect to the two contrast conditions tested.

Second, the typical spurious image pattern was observed in the 0.5:1, 1:1, and 2:1 targets. The images of the 3:1 targets produced a spurious pattern similar in structure, but difficult to detect. The images of the 5:1 and 7:1 targets showed no detectable spurious pattern, but only a uniformly exposed central area. This was the case for both the high and low contrast conditions.

Resolving power data was produced with an exposure series of five images, made with each target. The limits of the resulting image densities for each series was similar. All images of each series were examined with the microscope fitted with the filar eyepiece. Each image had a central "well" or exposed area, where the radial lines merged, containing no discernable image. The diameter of this nearly circular pattern was measured in three directions, orthogonally and along one diagonal. These diameter values were averaged together. Using this averaged value, target dimensions, and the image reduction value of the apparatus, the detectable number of lines per millimeter could be calculated. The highest value in lines per millimeter for each series was determined to be the resolving power for that target. The images that were examined and produced the resolving power values had similar central image density values, ranging from 0.46 to 0.51.

The resolving power series curves are similar in shape for both the Tri-x and the high contrast 5069 films. Both groups of data show that the 5:1 target produced the highest resolving power number.

The plots of the Fourier transforms of the crenelate representations of the targets show that the targets having the higher space width to line width ratios have no negative components until the high harmonic frequencies are reached, whereas the 1:1 ratio has a negative component for the second harmonic. A plot of the modulation of the average value d.c. component and the fundamental frequency versus the target ratios shows that the modulation increases as the lines become smaller relative to the width of the space between them.

DISCUSSION AND CONCLUSIONS

Observations, drawn upon the basis of the results of evaluating the data, lead to the conclusions that the pattern of the spurious image becomes undetectable in the 7:1 and 5:1 radial targets. The resolving power number increases to a peak near the 5:1 target and then starts to decline. This result is similar to that reported in Sandvik's bar target study. As he suggested, a radial target can be made to yield a resolving power value comparable to the 1:1 ratio bar target. The rise in the calculated value of modulation, using the average value and the first harmonic of the Fourier analysis, as one approaches the 7:1 target ratio, suggests that the detectability of the images would be greater for those targets as one approaches the resolution limit. These two components of the Fourier analysis were chosen since when the resolution limit is reached, it is believed that the image has usually degraded to these two components.

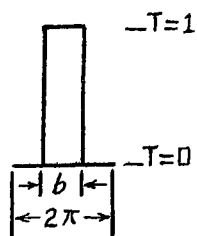
The spurious resolution pattern remained constant over the range of target ratios tested and at the two contrast levels. This tends to confirm the conclusions of Perrin, that the phenomena is related to the optical system used, more than to other factors, assuming a 1:1 target ratio. The fact that no spurious pattern was detected for the 7:1 and 5:1 targets might be partly explained by the relatively low harmonic amplitudes of the spectral components of those target patterns, and partly by the inability of the eye to detect modulation below a

certain threshold.

The resolving power values were highest for the 5:1 target for both films used. The crenelate analogue suggests that only the average value (d.c. component) and the first harmonic are present at the resolution limit. However, the plot of the sum of the first three harmonic amplitudes reaches a peak value for the 5:1 target. Possibly harmonics higher than the first play a significant part in interpretation of the observed image at the resolution limit. The crenelate analogue might be considered only as a first approximation of the radial target, and a mathematical analysis of the actual radial target is suggested.

The exposures necessary to produce images on the films increased in length up to a maximum of five times the exposure of the 1:1 radial target. This occurrence lead to the following thoughts on the subject.

The crenelate analogue of the radial target previously mentioned has the following formula for spectral composition: $X(t) = \sum_{N=0}^{\infty} C_N e^{jN\omega_0 t}$. The power in the signal is the square of the amplitudes in that Fourier series. The total signal power per period in the crenelate pattern is expressed as $C_0^2 + 2 \sum_{N=1}^{\infty} C_N^2$ power. If a film is exposed with a crenelate pattern



Transmittance pattern.

Figure 7.

having a transmittance altering between zero and one, as shown, and the frequency becomes high enough, the film does not respond to the period, and the average illuminance will be $E' = E \cdot b$. The effective exposure of the unresolved pattern is $E \cdot b$. If patterns of different b values (line to space ratios) are compared, the illuminance E , must be inversely proportional to b : $E \propto 1/b$,

or, for simplicity, $E = 1/b$. Dimensional analysis shows E to be power.

If the E value for the 1:1 target is called unit power E' , it can be said that if the effective exposure of each pattern is equal, then we deal with a signal of unit power, independent of the width of b . However, b does affect the spectral composition of the power spectrum. This is shown in the graphs on page 20.

Even though the calculated detectability increases beyond the 5:1 target, the actual image detectability, and resolving power, fall off. It has been suggested that the modulation transfer function of the eye and/or film might, principally, account for the maximum resolving power number occurring at the 5:1 radial target ratio, but the reasons are not known at this time.

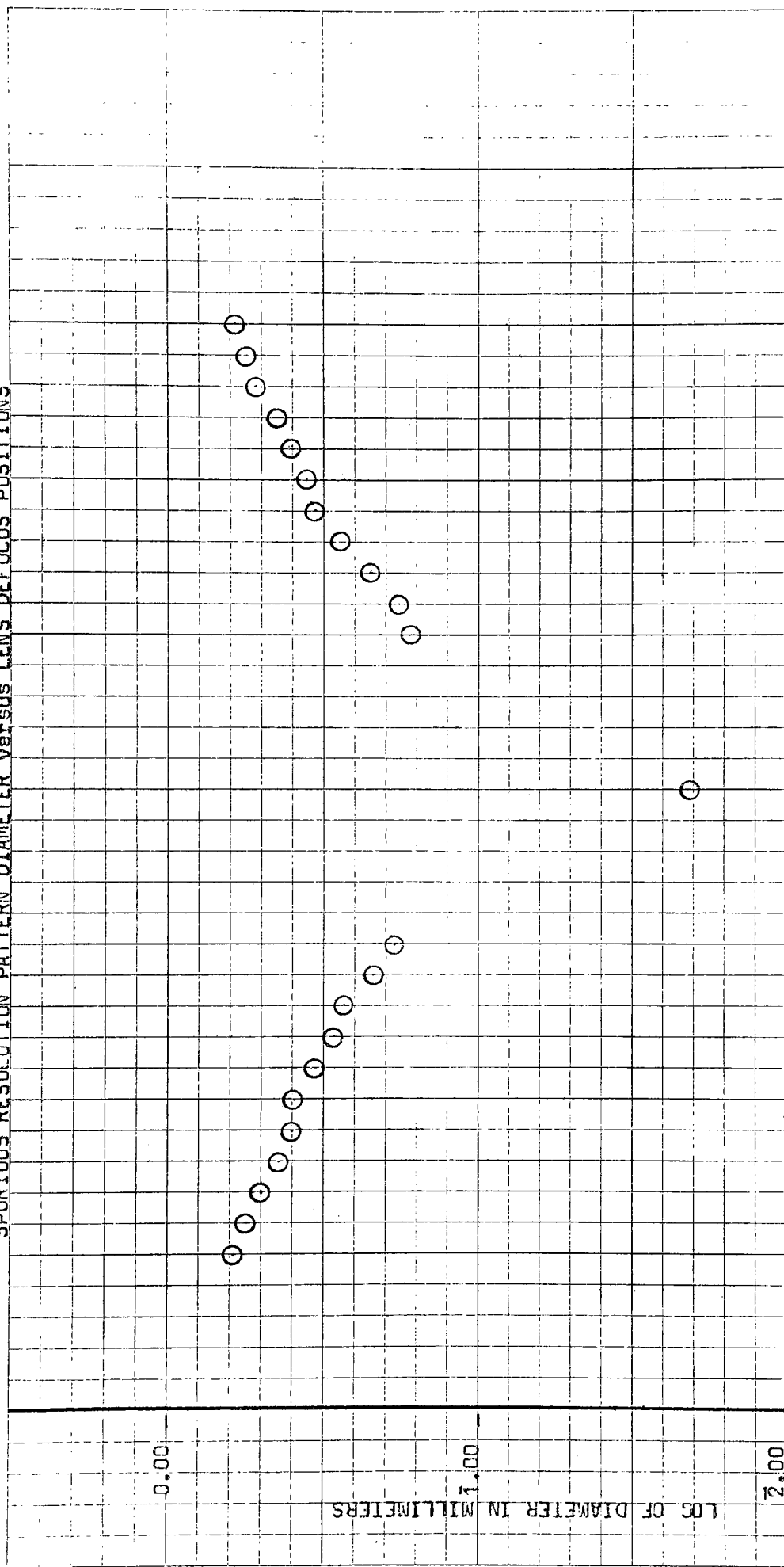
Summarizing, the data shows that spurious resolution is undetected in radial patterns having space width to line width ratios in excess of 5:1. The resolving power number is higher in the 5:1 target, supporting Sandvik's suggestion that a radial target with a ratio other than the conventional 1:1 ratio would produce resolving power values comparable to bar targets. Comparing the transforms of the crenelate analogues and observing the actual transform of the radial target (see appendix) in comparison with the transform of the three bar target, suggest that the radial targets in general, and the 5:1 radial target in particular, conform, more completely, to actual images encountered in practice, and the 5:1 target produces resolving power values comparable to the tri-bar target.

The results of the resolving power tests and the spurious resolution effect observations suggest possible future work in both areas. The resolving power work should be extended to include a low contrast

evaluation for the purpose of comparison with the high contrast results already obtained. A thorough mathematical analysis of the radial targets and their transforms is in order. The product of that effort would provide information pertinent to interpretation of the results of this project. The absence of the familiar spurious image with the 5:1 and 7:1 targets invites more tests with other lenses and films to see if the effect is still absent in "field test" situations where the 1:1 radial target and the standard tri-bar target produce this unwanted effect.

The results of this project indicate that the 5:1 radial target is preferable to the standard tri-bar target in a lens test or a resolving power test because the spurious resolution phenomenon is effectively eliminated and the target signal contains information more readily analogous to most practical imaging situations.

SPURIOUS RESOLUTION PATTERN DIAMETER VERSUS LENS DEFOCUS POSITIONS



LENS POSITION EXPRESSED IN RELATIVE DEGREES ON PROTRACTOR

-15° -10° -5° 0° +5° +10° +15°

LOG OF DIAMETER IN MILLIMETERS

0.00 1.00 2.00

No spurious pattern occurred within +5 and -5 of best focus (0).

0 is best focus position. Data point represents diameter of central unresolved image.

The minus ten degree position was used for the exposure series.

Figure 8

KODAK 5069 HIGH CONTRAST COPY RESOLVING POWER VERSUS LOG OF LINE TO SPACE WIDTH RATIO

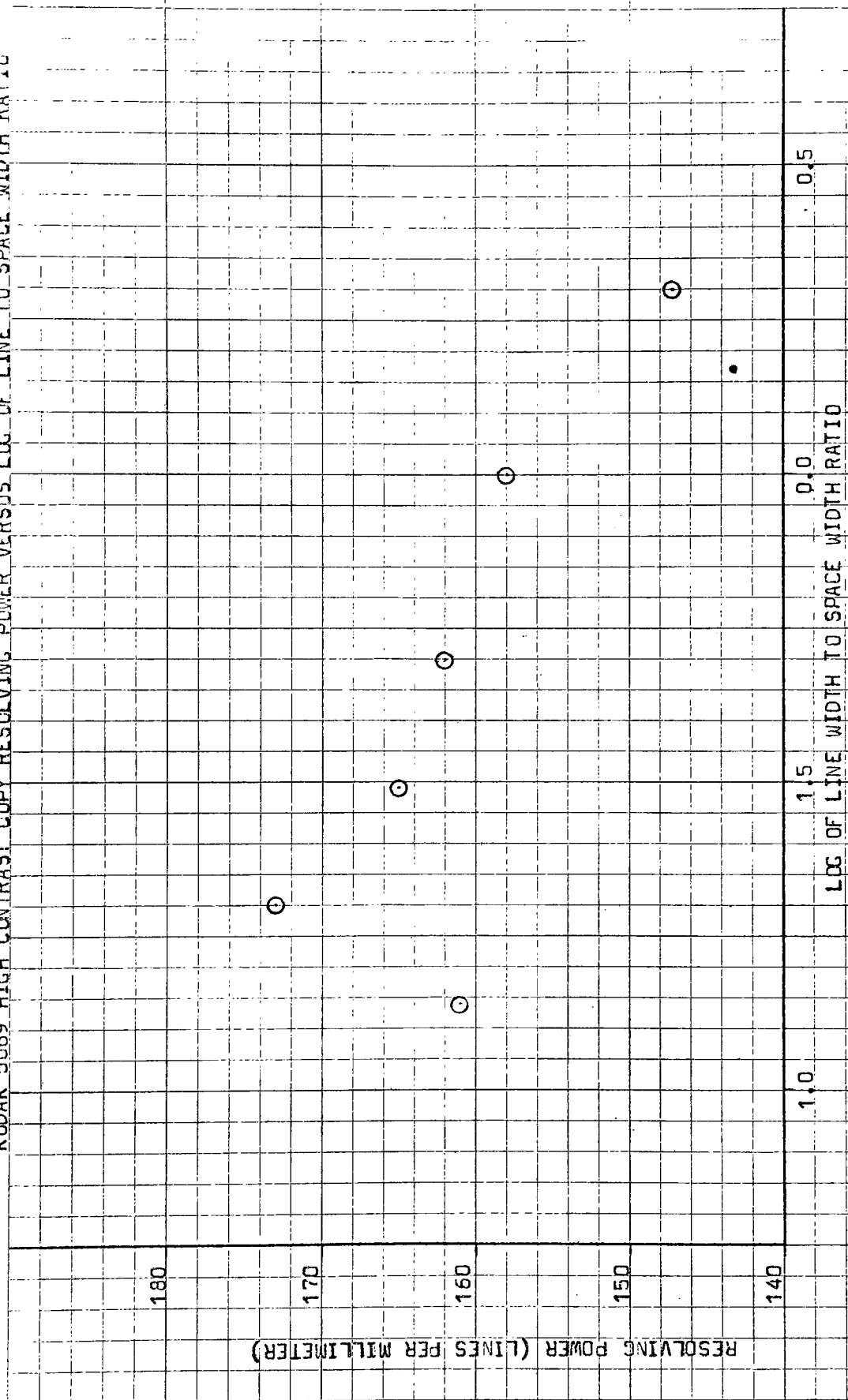


Figure 9

KODAK TRI-X RESOLVING POWER VERSUS LOG OF LINE TO SPACE WIDTH RATIOS

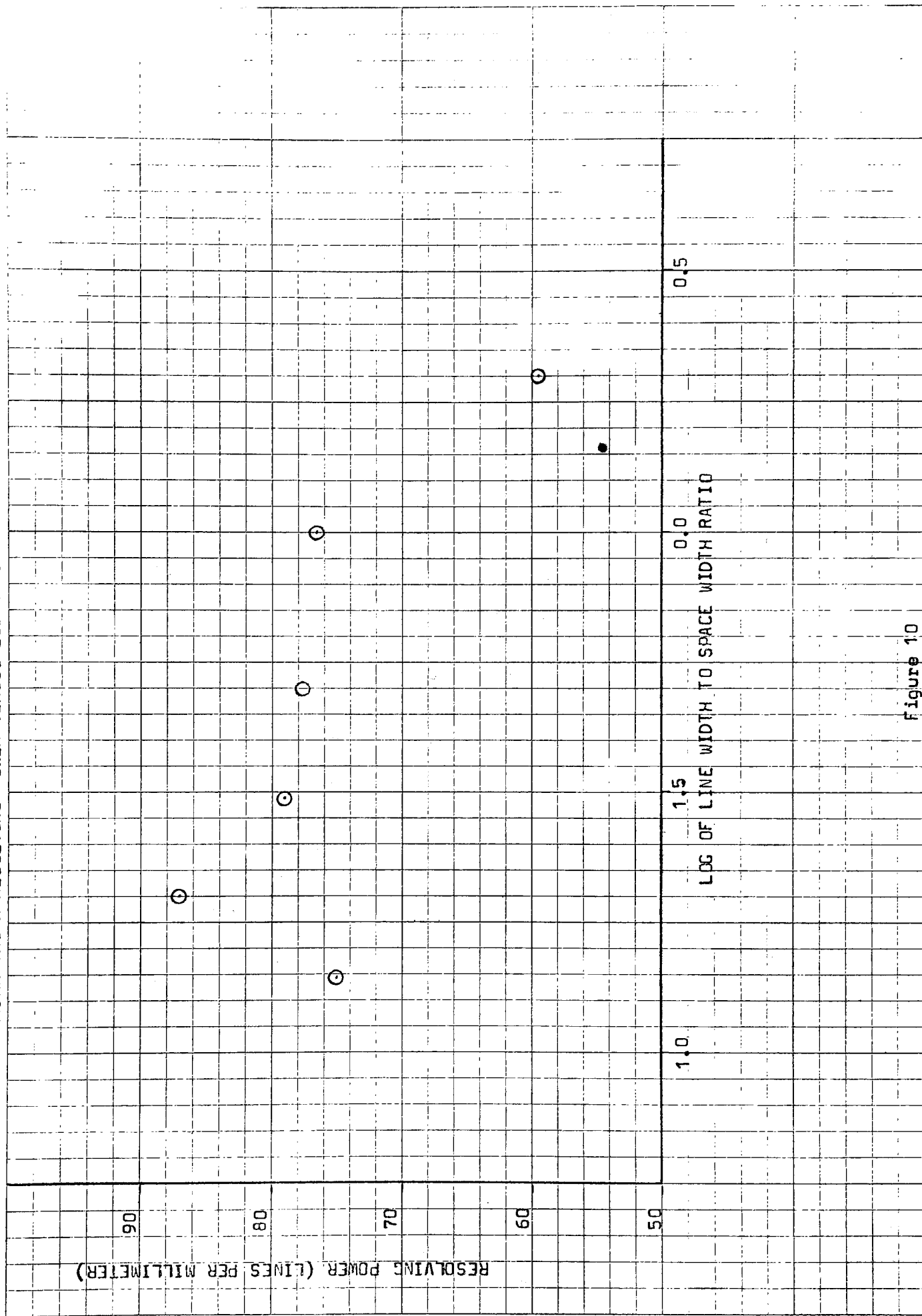
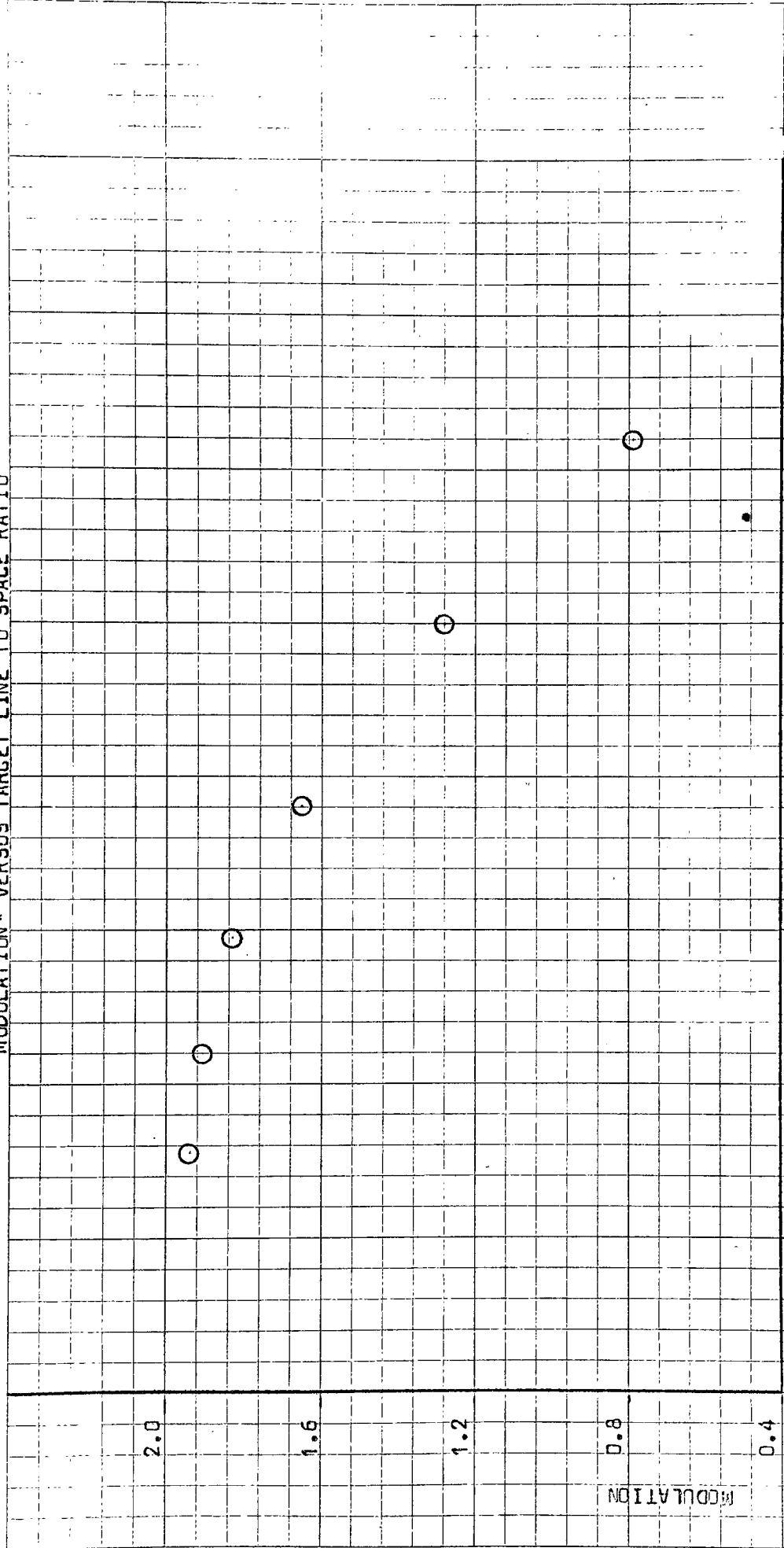


Figure 10

MODULATION* VERSUS TARGET LINE TO SPACE RATIO



* Modulation number obtained using the average value and first harmonic values of Fourier series of targets.

Figure 11

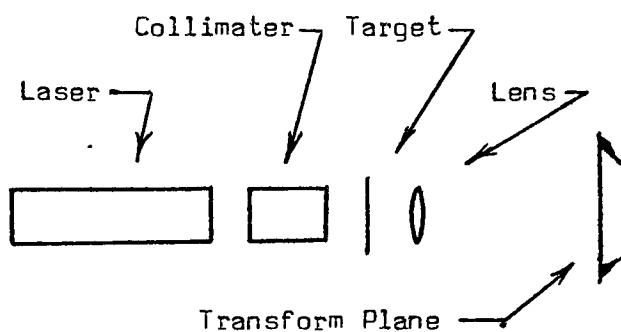
APPENDIX

APPENDIX

Description of Observed Radial Target Transform

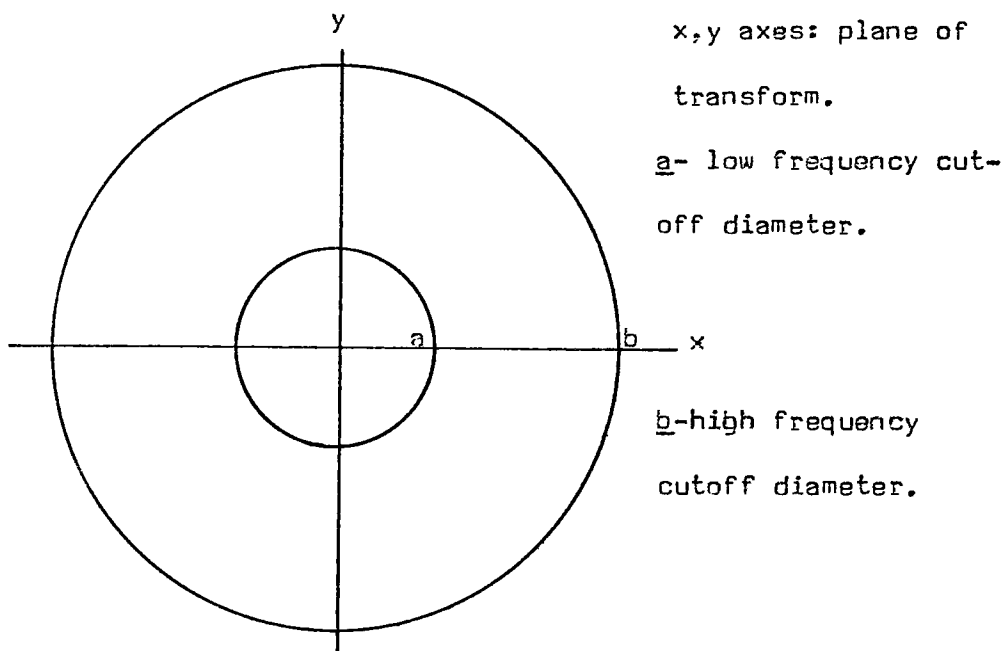
The radial target was placed in a collimated laser beam apparatus to observe the transform pattern. The apparatus is diagrammed in figure 12. The transform for the 1:1 target appeared as a doughnut-shaped pattern, as represented in figure 13. Traveling along the diameter represented by the x-axis, the light intensity was observed to be zero at the origin and remained so until point (a), which marks the inner diameter of the pattern. The light intensity at point (a) was at its maximum value and fell off to zero as one continued outward on the diameter to point (b). The intensity was concentrically uniform, referenced to the origin.

The 5:1 target transform pattern would be similar except for a relatively lower light intensity throughout the pattern. The high frequency limit of the target is represented by the outside diameter of the transform pattern. The low frequency cutoff is determined, in the target, by the outside of the target, and is represented, in the transform, by the inside diameter.



Schematic Diagram of Apparatus Used to Observe Transform

Figure 12

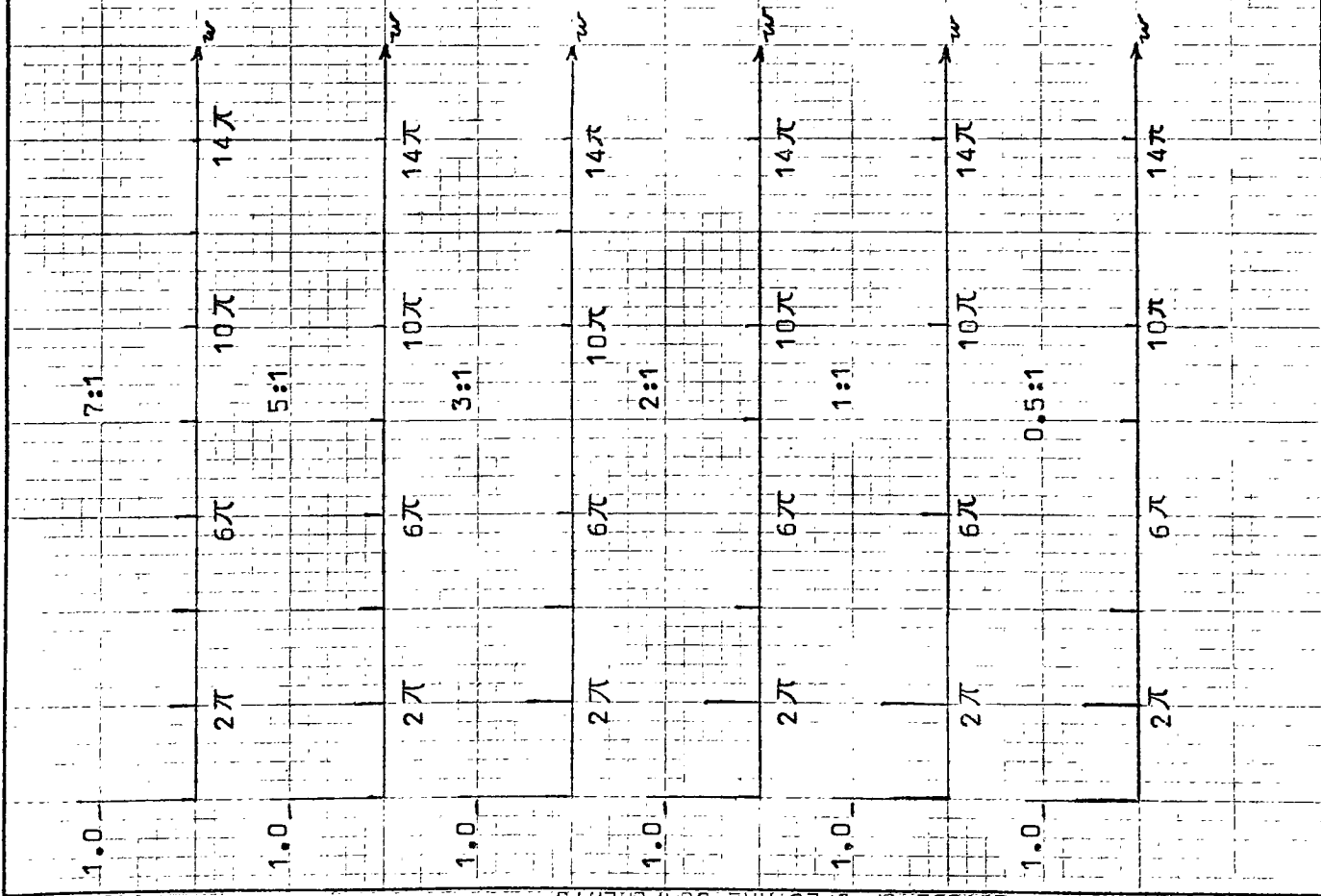


Representation of Transform of 1:1 Radial Target

Figure 13

FREQUENCY SPECTRA AT A FIXED FREQUENCY OF THE CRENELATE

ANALOGUES OF TARGETS USED IN TESTING



FOURIER TRANSFORM AT A FIXED FREQUENCY OF CRENELATE

ANALOGUES OF TARGETS USED IN TESTING

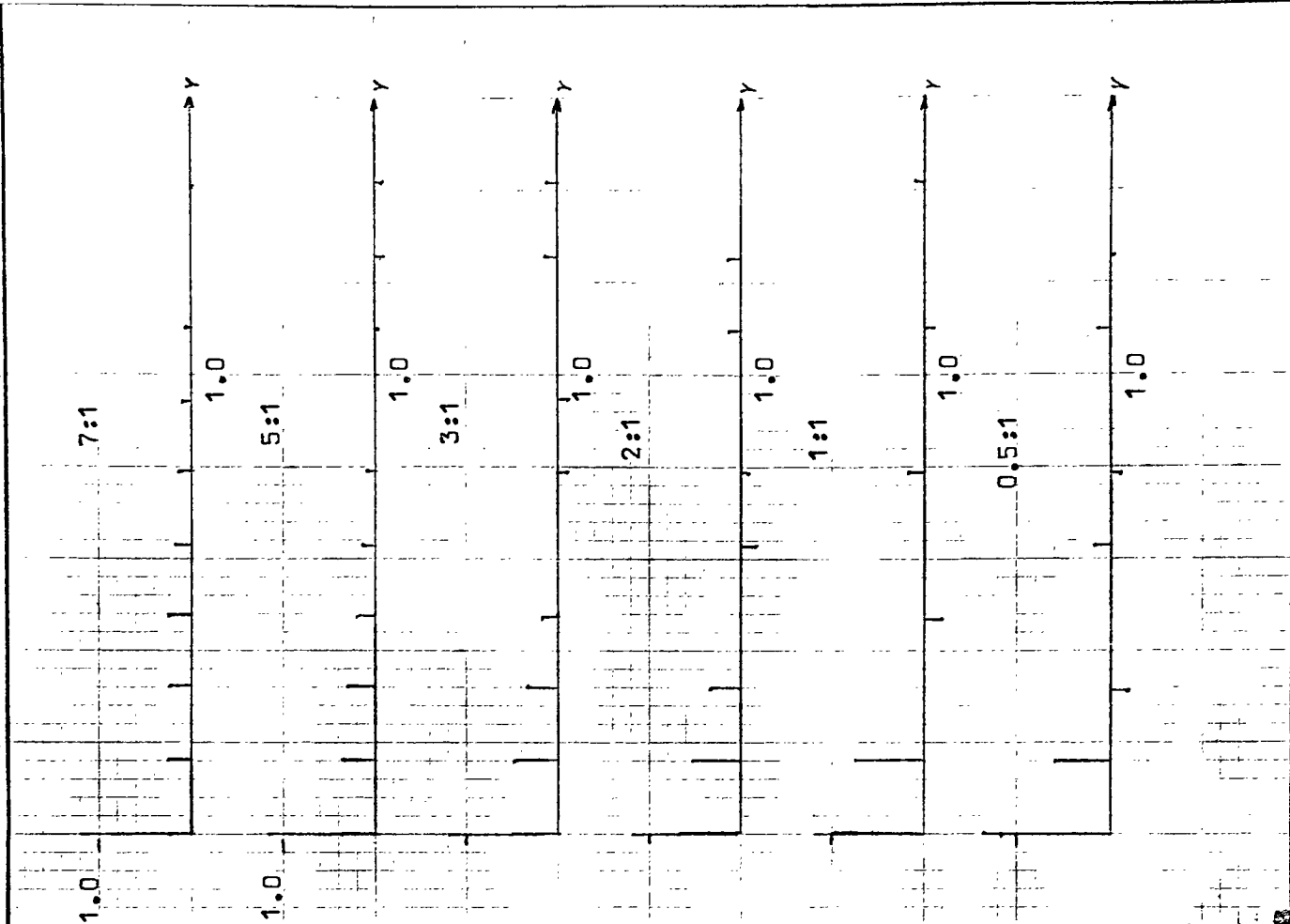


Figure 14

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